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Review on matrix thermal absorber designs for solar air collector

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ABSTRACT

Solar thermal absorber is the main component of solar air collector. It absorbs solar radiation and converting energy received to thermal energy and transferring the energy by means of convection to working fluid, producing elevated air temperature output. Among thermal absorber used in solar air collector applications, permeable matrix thermal absorber is one of the promising thermal absorbers that delivers high thermal efficiency. Absorber topology, flow routing and materials contribute a significant portion towards thermal performance and overall thermal efficiency of collector and many research are being actively done in these areas. This review shall focus on the advances of topology designs, enhancement methods, thermal performance and absorber materials currently available for matrix type of solar air collector. Essential attributes influencing thermal performance of solar air collector with matrix absorber are also highlighted in this article.

Contents

1. Introduction

Energy has become one of the most important issues in the world. The fossil energy source in the form of petroleum and coals are being used extensively. The energy crisis, which is caused by the decrease of energy resources have led to the instability of the world politically and economically [1]. Open fossil fuel burning causes harmful emission gases to be released to the atmosphere, which detrimentally affects the environment and the existing natural ecosystem as well as contributes to the global warming [2,3]. To mitigate the rising environmental problem due to excessive use of fossil fuels, interest towards renewable energy sources among world community has increased significantly and many types of research have been pursued to harness such energy form particularly in the solar energy area. Solar energy is the most

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abundant renewable energy available to the earth and it exists in direct and indirect forms. It is approximated that 3,400,000 EJ of solar radiation reaches the earth surface annually, which is much greater than all non-renewable energy combined [4]. With this notion, solar energy is seen as one of the future ultimate solution to the energy shortage and crisis of the world.

In conventional electrical heating which is widely used in industries, heating element consists of conducting metal is attached to the electrical circuit and current flow through the metal will generate heat. The heat will be transferred to the air by forced convection to produce hot air for industrial use. Essentially, the heating element is converting the electrical energy to thermal energy. By replacing or adding solar air collector to the drying system to produce hot air, higher energy savings can be achieved in addition to lower maintenance cost for solar air collector [5]. Various processes can benefit from solar air drying, for example, crops drying and industrial products such as textile, bricks and dairy products [6].

Solar thermal absorbers surface converts received solar radiation into thermal energy [7,8]. To extract the converted thermal energy into useful energy, direct heating of material is possible as well as supplying heat transfer medium i.e. water and air to the absorbers and allowing convection heat transfer to take place. Heated heat transfer medium is then supplied and can be utilised for any thermal application.

Solar energy has flexibility for storage where the converted thermal energy can be stored in the form of sensible heat, latent heat or chemical energy [9]. The stored energy is used to increase the reliability of solar thermal system especially during irregular weather condition such as cloud and haze, which can interrupt solar radiation [10]. Specific heat capacity for the material per volume is important as it will dictate the size and space of absorber material.

Solar air collectors are mainly categorised according to its operating temperature range of low, medium and high temperature [11] as well as type of solar radiation receiving surface of the collector namely concentrating and non-concentrating type [12]. A concentrating solar air collector generally employs concave reflector designs in order to focus solar radiation into a smaller receiving area and subsequently increase radiation flux, while a non-concentrating collector uses the solar thermal absorber which defines the solar thermal collector area for intercepting and absorbing solar radiation [13]. Solar air collectors can be further differentiated by the heat transfer medium, and the two most common medium are air and water. When overall costing is taken into consideration, air based solar collector is more economical compared to water-based solar collector due to the use of cheaper material and uncomplicated fabrication process in addition to its lower maintenance cost [14]. However, the downside of air based solar collector is the lower specific heat capacity of air, which is four times lower than water, and with relation to thermal conductivity and diffusivity (Table 1), higher thermal energy is required to produce output temperature similar to water based collector. It is worth to note that the flow behaviour of water is relatively easy to predict and to determine as its flow uniformity in most cases can be controlled as opposed to air [15]. One major advantage of solar air collector is the components practically have no corrosion, no abrasion and no leaking which is normally the case for water based solar collector.

Table 1.
Thermo-physical properties of water and dry air [89,93].

	Water	Air
Specific heat capacity, J/g K	4.180	1.007
Thermal conductivity, W/m K	0.5985	0.0259
Thermal diffusivity, m²/s	1.43×10^{-7}	1.9×10^{-5}

This paper provides an overview of solar air collector with matrix thermal absorber with a focus on the matrix absorber design and performance. Coverage is also given on types of absorber material of flat absorber collectors to facilitate the selection of material for solar air collector application, specifically for matrix absorber solar air collectors.

2. Thermal absorber design

The function of solar thermal absorbers material is to absorb, to store and to transfer the thermal energy received from solar radiation to heat transfer medium such as air and water. Its performance relies on the material type and its thermo-physical properties as well as coating of the absorber surface. Air has heat transfer coefficient value four times lower compared to water and this directly affects the heat transfer performance when it comes to transferring heat between absorber plate and the flowing air. In order to enhance the efficiency, various designs of absorbers and enhancement have been proposed. According to Chamoli et al. [16], three methods that can be used to enhance the heat transfer for air solar absorber are the implementation of secondary heat transfer surface, disruption of the unenhanced fluid velocity and disruption of the laminar sub-layer in the turbulent boundary layer. By introducing turbulent flow in the flow path of the solar air collector, a significant increase of collector performance is recorded [17–20]. This is due to higher heat transfer coefficient and increased contact surface between air and absorbers which increase the heat transport from the absorber to heat transfer fluid.

According to Norton [21], solar air collectors can be classified according to its movement on axis as well as the type of absorbers used in the solar air collector and base design geometry namely flat absorbers, tubular absorbers and point absorbers. Further differentiation for solar air collector with flat absorbers, also known as non-concentrating absorber, can be made based on the physical properties of the absorbers, which are non-permeable or permeable absorbers. Thermal absorber design for stationary flat absorber is based on bare-flat plate orientation where it lies on the flat plane with no concentrating points. Non-permeable absorbers indicate the flat absorbers with non-permeable material and that it is possible to have extended versions of this absorber e.g. corrugated, finned and/or assistance of flow redirection. The enhancement method of permeable absorbers are the same as non-permeable absorbers except that it has two absorber sub-types which are matrix/meshes and perforated type.

The classical design of solar absorber as mentioned by Duffie and Beckman [22] are flat plate, V-groove and matrix/meshes. From these base designs, a few variation of new absorbers were invented to increase the performance of solar air collector. The combination of multiple enhancement designs further improve the performance of solar air collectors but there also risks of performance decline if the solar thermal absorber is not properly designed [23,24]. Absorber enhancement can be generalized into two common types which are corrugated and finned. Further enhancement can expand into flow redirection method where air inflow in the solar air collector is diversified by means of diversion of air flow path.

Absorber designs with significant efficiency improvement over conventional flat-plate solar air collector have been proposed by various authors [25–32]. With more advanced and complex design of absorbers, the cost of fabrication and manufacturing would also increase. Performance of solar air absorbers is greatly influenced by the air flow behaviour in the solar air collector. Four types of air flow redirection applicable for solar air collectors designs are